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Soil organic matter pools with conventional and zero tillage in a cold, semiarid climate

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Abstract

Conservation of soil organic matter (SOM), especially in high-SOM surface soils of the Canadian Prairies, is essential for maintaining soil quality and regulating soil CO_2 emissions. We determined the depth distribution (0–50, 50–125, and 125–200 mm) of soil organic C (SOC), soil microbial biomass C (SMBC), basal soil respiration (BSR), and net N mineralization in four Boralfs subjected to shallow conventional tillage (CT) and zero tillage (ZT). Tillage regimes were initiated 4, 4, 7, and 16 years prior to these measurements on a limed clay loam, unlimed clay loam, loam, and silt loam, respectively, located in northern Alberta and British Columbia. Soils under ZT were an average of 4% denser and 24% wetter than under CT. SOC content to a depth of 200 mm was 6.5 kg m^{-2} under CT and 11% greater under ZT in the limed clay loam, but not different between tillage regimes in the unlimed clay loam (7.1 kg m^{-2}), silt loam (5.1 kg m^{-2}), and loam (4.3 kg m^{-2}). BSR averaged 4.0 and 3.1 g CO_2-C per square meter per day under CT and ZT, respectively. The portions of SOC and SMBC as BSR under ZT were lower than under CT. However, net N mineralization averaged 3.4 and 4.1 g m^{-2} per 24 days under CT and ZT, respectively. The cold, semiarid climate of the Canadian Prairies appears to have hindered any acceleration of decomposition of SOM and crop residues owing to soil disturbance with CT. Therefore, SOC and active soil C pools were not enriched by minimized soil disturbance, unlike results obtained from more temperate and humid climates.

Keywords: Carbon mineralization; Microbial biomass; Nitrogen mineralization; Organic matter; Semiarid; Tillage

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1. Introduction

Alteration of the quantity and quality of soil organic matter (SOM) with conservation tillage systems can have an impact on numerous physical, chemical, and biological properties that influence soil moisture characteristics, nutrient availability, and above- and below-ground biotic activity (Frede et al., 1994; Karlen et al., 1994). In the past decade, zero tillage (ZT) and various reduced tillage management systems have received increased attention owing to the potential of these management systems for abating soil erosion, conserving soil moisture, enhancing water quality, and cutting monetary and energy inputs of crop production systems (Blevins and Frye, 1993; Hatfield and Stewart, 1994).

SOM has been reported to increase by 0–7% per year in semiarid regions with long-term use of conservation tillage compared with conventional tillage (CT) (Rasmussen and Collins, 1991). The large variance in the effect of tillage on SOM in the semiarid region has not been adequately explained, but may be due to differences among locations in initial SOM content, plant productivity, precipitation distribution, and/or soil temperature. More research is needed to understand why such large differences in total SOM alteration owing to tillage regime exist. Measurement of the more active fractions of SOM, such as soil microbial biomass C (SMBC) and mineralizable C and N, may provide a more sensitive appraisal and an earlier indication of tillage and crop management effects on SOM content (Biederbeck et al., 1994).

Adoption of conservation tillage in the Canadian Prairies is increasing (Larney et al., 1994). However, the limited data available on the effect of conservation tillage on SOM content in this cold, semiarid region is not consistent. Soil organic C (SOC) and total N were 26% greater following 10 years of ZT compared with CT at a depth of 0–75 mm in a silt loam from British Columbia (Arshad et al., 1990). Mean SOC content of four soils from Saskatchewan and Alberta was not different between CT and ZT (Carter and Rennie, 1982). In this study, the portion of SOC as soil microbial biomass SMBC was greater under ZT to a depth of 100 mm in a clay loam, but not different between tillage regimes in the other three soils. SMBC and N were often higher under ZT than under CT in the surface 20–50 mm, but lower below the surface layer (Carter and Rennie, 1982). The depth of measurement of SOM varied among locations in these studies, which may explain some of the variance that occurred among locations. Whereas SOM has been frequently found to increase by 50% and more within the surface 50–75 mm of soil in temperate, humid regions (Dick, 1983; Doran, 1987; Franzluebbers, A.J. et al., 1994), low annual temperature and significant moisture deficit in soils of the Canadian Prairies may (i) limit the amount of C input necessary to support a steady-state SOC level and (ii) limit the acceleration of decomposition owing to soil disturbance under CT.

Our objectives were to (i) determine the depth distribution of total and active SOM pools and (ii) investigate if the relationships between the smaller, more active SOM pools and total SOC could be used as a more sensitive indicator of potential changes in SOM owing to tillage management from four soils in the cold, semiarid Canadian Prairie region.

2. Materials and methods

2.1. Site characteristics and crop management

Field experiments comparing CT and ZT management were initiated: on a Hythe clay loam (fine-loamy, montmorillonitic, frigid Mollic Cryoboralf) near Beaverlodge, Alberta (55° 11′ N, 119° 32′ W) in 1991; on a Donnelly silt loam (fine-loamy, mixed, frigid Typic Cryoboralf) near Dawson Creek, British Columbia (55° 46′ N, 120° 21′ W) in 1979; and on a Donnelly loam (coarse-loamy, mixed, frigid Typic Cryoboralf) near Rolla, British Columbia (55° 42′ N, 120° 10′ W) in 1988. To a depth of 125 mm, average clay content was 31% in the Hythe clay loam, 25% in the Donnelly silt loam, and 17% in the Donnelly loam. Mean annual temperature was 2.0 and 0.9°C, and mean annual precipitation was 452 and 504 mm at Beaverlodge and Dawson Creek, respectively. The moisture deficit at Beaverlodge averages approximately 550 mm based on pan evaporation from May to September (P. Mills, personal communication, 1995) and is likely similar at Dawson Creek (data not recorded).

Conventional tillage at all locations consisted of one cultivation (100–150 mm depth with 100 mm-wide chisels) after harvest, followed by two cultivations (70–100 mm depth with 100 mm-wide chisels) in the spring prior to seeding. ZT consisted of harrowing following the harvest to evenly distribute straw, and spraying glyphosate to control weeds prior to seeding. Crop sequences were canola (*Brassica campestris* L.) barley and (*Hordeum vulgare* L.) barley on the Hythe clay loam, continuous barley on the Donnelly silt loam, and canola-barley-wheat (*Triticum aestivum* L.) on the Donnelly loam. All crops were sown in mid-May with a double-disc press drill in 170 mm wide rows and harvested in September. Fertilization regimes generally consisted of a starter fertilizer (1.4 g N and 0.8 g P per square meter) applied with the seed at 38 mm depth and supplemental N (5.5–6.5 g N per square meter) applied as a side band at 50 mm depth. Barley grain yield in 1994, averaged across locations, was $371 \pm 36\,g\,m^{-2}$ under CT and $371 \pm 17\,g\,m^{-2}$ under NT.

The experimental design was a randomized, complete block with four replications on the Hythe clay loam. Treatments consisted of a factorial arrangement of tillage and liming in plots measuring 3 m × 15 m. Lime (250 g $CaCO_3$ equivalent per square meter) was incorporated in May 1991 to raise the pH (1:1, soil:water) from 5.3 to 6.7. The experimental design consisted of paired plots with three locations in adjacent fields of CT and ZT on the Donnelly silt loam and four locations on the Donnelly loam. Plots (20 m × 50 m) were separated by 150 m to account for potential soil variability owing to slope (1–3%) position within the fields (Shapiro et al., 1989).

2.2. Soil sampling

Soil samples consisted of eight soil cores (25 mm diameter) per plot sectioned into depth increments of 0–50, 50–125, and 125–200 mm that were collected in early May 1995 prior to spring field operations, except in CT on the Donnelly loam when seeding and fertilization took place a few days prior to sampling. Cores were collected equidistantly (2 m in the Hythe clay loam soils and 5 m in the Donnelly silt loam and loam soils) along a diagonal transect within each plot. Soil was air-dried and gently crushed to pass a 5.6 mm screen to remove large stones.

2.3. Soil physical and chemical properties

Soil bulk density was calculated from an oven-dried subsample (60°C, 48 h) and volume of the coring device. Water-filled pore space ($m^3\ m^{-3}$) was calculated from the equation:

$$\text{water-filled pore space} = \text{SWC} \times \text{BD}/(1 - \text{BD}/\text{PD})$$

where SWC is soil water content ($kg\ kg^{-1}$), BD is bulk density ($Mg\ m^{-3}$), and PD is particle density (assumed 2.65 $Mg\ m^{-3}$). Inorganic soil N was determined from a 5 g subsample that was passed through a 2 mm screen and shaken with 10 ml of 2 M KCl for 1 h. The filtered extract was analyzed for NH_4-N and NO_3-N + NO_2-N using autoanalyzer techniques with a modified indophenol blue method with citrate buffer and a Cd reduction method, respectively (Bundy and Meisinger, 1994). SOC was determined using the modified Mebius method in digestion tubes (Nelson and Sommers, 1982). The total C:N ratio of the 0–50 mm depth collected in 1994 did not differ appreciably (10.0 ± 0.5 under CT and 11.4 ± 1.4 under ZT) (M.A. Arshad, unpublished data, 1995).

2.4. Soil biological properties

Carbon mineralization was determined from a 40 g subsample of soil in a 50 ml beaker and a 20 g subsample of soil in a 30 ml beaker placed in a 1 L canning jar along with vials containing 10 ml of 0.55 M NaOH to trap evolved CO_2 and water to maintain high humidity. Soil was moistened to near field capacity (0.3 g water per gram for the Hythe clay loam and the Donnelly silt loam and 0.25 g water per gram for the Donnelly loam) and incubated at 25°C for 24 days. Alkali traps were replaced at 3 and 10 days and CO_2-C evolved determined by titration (Anderson, 1982). Basal soil respiration (BSR) was estimated as the rate of CO_2-C evolved from 10 to 24 days. After 24 days incubation, the soil was oven-dried (60°C, 24 h) and passed through a 2 mm screen. Inorganic N concentration of the soil incubated for 24 days was determined in the same manner as described previously for initial inorganic soil N. Net N mineralization was calculated from the difference in inorganic soil N between 0 and 24 days. At 10 days of incubation, the 20 g subsample was removed, fumigated with chloroform, and incubated in a separate canning jar at 25°C for 10 days. SMBC was calculated from the CO_2-C evolved following fumigation, assuming an efficiency factor of 0.41 (Voroney and Paul, 1984).

2.5. Statistical analyses

Variance in soil physical, chemical, and biological properties within each soil type and soil depth was analyzed with the general linear model procedure of SAS Institute Inc. (1990). Variance in soil properties averaged across the four soils was analyzed in the same manner using mean values for each soil type. Sensitivity of each soil property to variation in blocking and tillage treatment was evaluated using the overall model F-value as an indicator. Soil depth increment (0–50, 50–125, 125–200, and 0–200 mm) and site were used as replications to test for significance.

3. Results and discussion

3.1. Soil physical and chemical properties

Soil bulk density at a depth of 0–50 mm was greater under ZT than under CT in the two clay loams, but not different between tillage regimes in the silt loam and loam

Table 1
Soil physical, chemical, and biological properties as affected by soil depth, soil type, and tillage regime

Soil type	0–50 mm		50–125 mm		125–200 mm		0–200 mm	
	CT	ZT	CT	ZT	CT	ZT	CT	ZT
Soil bulk density ($Mg\,m^{-3}$)								
Hythe clay loam (limed)	0.85 **	0.99	1.05 ***	1.11	1.26	1.30	1.08 *	1.15
Hythe clay loam (unlimed)	0.84 *	0.97	1.02 *	1.11	1.26	1.23	1.07	1.12
Donnelly silt loam	0.97	0.86	1.16	1.23	1.28	1.32	1.15	1.17
Donnelly loam	1.00	1.02	1.23 **	1.35	1.37	1.38	1.23	1.28
Mean	0.91	0.96	1.11 **	1.20	1.29	1.31	1.13 *	1.18
Water-filled pore space ($m^3\,m^{-3}$)								
Hythe clay loam (limed)	0.26 **	0.51	0.50 *	0.60	0.60	0.64	0.48 **	0.59
Hythe clay loam (unlimed)	0.25 **	0.47	0.50 **	0.61	0.62	0.61	0.48 **	0.57
Donnelly silt loam	0.20 *	0.28	0.37 **	0.51	0.47 *	0.53	0.36 *	0.46
Donnelly loam	0.21 *	0.33	0.40 *	0.54	0.43 *	0.52	0.36 *	0.48
Mean	0.23 *	0.40	0.44 ***	0.56	0.53	0.57	0.42 ***	0.52
Inorganic soil N ($g\,m^{-2}$)								
Hythe clay loam (limed)	1.63 *	2.06	2.11	2.11	1.57	1.68	5.31 *	5.84
Hythe clay loam (unlimed)	1.77	2.30	2.91	2.09	1.98	1.73	6.66	6.12
Donnelly silt loam	1.38	1.79	1.90	1.94	1.53	1.60	4.82	5.33
Donnelly loam	3.84 **	1.73	3.75 *	2.43	2.93 *	2.38	10.53 **	6.53
Mean	2.15	1.97	2.67	2.14	2.00	1.85	6.83	5.95
Net N mineralization ($g\,m^{-2}$ per 24 days)								
Hythe clay loam (limed)	1.06 **	1.70	1.33	1.61	0.58	0.67	2.96	3.99
Hythe clay loam (unlimed)	1.51	2.00	1.80	1.73	0.94	0.56	4.26	4.29
Donnelly silt loam	1.67	2.53	1.44	1.33	0.92	0.64	4.03	4.49
Donnelly loam	0.65 *	1.87	1.36	1.21	0.44	0.53	2.44 *	3.60
Mean	1.22 **	2.02	1.48	1.47	0.72	0.60	3.42 *	4.09
Cumulative C mineralization ($g\,m^{-2}$ per 24 days)								
Hythe clay loam (limed)	60.1	51.2	41.6	41.9	24.7	19.8	126.4	113.0
Hythe clay loam (unlimed)	66.7 ***	47.3	40.5 *	31.1	25.8	22.0	133.0 **	100.5
Donnelly silt loam	56.8	51.3	42.9 **	34.3	29.3	28.3	128.9 *	107.9
Donnelly loam	59.9 *	41.7	26.8 *	21.2	14.2	13.9	100.9 *	76.9
Mean	60.9 *	47.9	37.9 *	32.1	23.5	21.0	122.3 **	99.6

*, **, and *** indicate significance between tillage regimes at $P \leq 0.1$, $P \leq 0.01$, and $P \leq 0.001$, respectively.
CT is conventional tillage; ZT is zero tillage.

(Table 1). The last tillage operation occurred seven months prior to sampling in October. At a depth of 50–125 mm, soil bulk density was consistently greater under ZT than under CT. No differences in soil bulk density between tillage regimes occurred in any of the soils at a depth of 125–200 mm. Increases, as well as, decreases in bulk density with ZT compared to with CT at the soil surface have been reported previously (Doran, 1987; Benjamin, 1993). The finer-textured clay loams may have been more prone to consolidation than the coarser-textured silt loam and loam, especially at the soil surface. In the shallow-tilled, northern soils of our study, soil bulk density at a depth of 0–200 mm was similar between tillage regimes in the silt loam and loam 16 and 7 years after initiation of tillage regimes, respectively, and 5–6% greater under ZT than under CT in the clay loams four years after initiation of tillage regime. In Minnesota, soil bulk density at a depth of 0–150 mm was greater under conservation tillage during the first three years of comparison with moldboard plowing, but less following this initial change (Voorhees and Lindstrom, 1984).

Water-filled pore space was consistently greater under ZT than under CT in the 0–50 and 50–125 mm soil depths (Table 1). At a depth of 0–200 mm, water-filled pore space ranged from 0.09 to 0.12 $m^3 m^{-3}$ greater under ZT than under CT. Very little rainfall occurred in the spring following the snowmelt prior to sampling, indicating that soil under ZT had a 19–33% greater capacity to retain water in the upper root zone than soil under CT. Greater water-filled pore space under ZT compared with CT is consistent with previous observations (Doran, 1987; Franzluebbers et al., 1995).

Inorganic soil N at a depth of 0–50 mm was 26–30% greater under ZT than under CT in the clay loams and the silt loam (Table 1). In the loam, inorganic soil N under ZT was less than half of that under CT, which was due to N fertilization in CT before soil sampling. There were no significant differences in inorganic soil N between tillage regimes at lower depths, nor at a depth of 0–200 mm in the unlimed clay loam and silt loam. Greater inorganic soil N at the soil surface under ZT may have been due to less plant N uptake at the surface, where N mineralized from surface residue decomposition accumulated.

SOC concentration at a depth of 0–50 mm was not different between tillage regimes in any of the four soils (Fig. 1). At a depth of 50–125 mm, SOC was lower with ZT than with CT in the silt loam, but was not different between tillage regimes in the clay loams and the loam. No differences in SOC concentration between tillage regimes occurred in the 125–200 mm depth. SOC content to a depth of 200 mm averaged 6.5 $kg\,m^{-2}$ under CT in the limed clay loam, but was 11% greater ($P < 0.01$) under ZT. No differences in SOC content to a depth of 200 mm between tillage regimes occurred in the unlimed clay loam (7.1 $kg\,m^{-2}$), the silt loam (5.1 $kg\,m^{-2}$), and the loam (4.3 $kg\,m^{-2}$). Our findings are similar to those of Carter and Rennie (1982), in that ZT appears to have a relatively small impact on SOC when compared with conventional-shallow tillage of annual crops in a cold, semiarid climate and in that statistical differences in SOC between tillage regimes are unlikely to occur before 16 years.

3.2. Soil biological properties

SMBC at a depth of 0–200 mm was not different between tillage regimes in any of the soils, averaging 198 $g\,m^{-2}$ in the limed clay loam, 181 $g\,m^{-2}$ in the unlimed clay

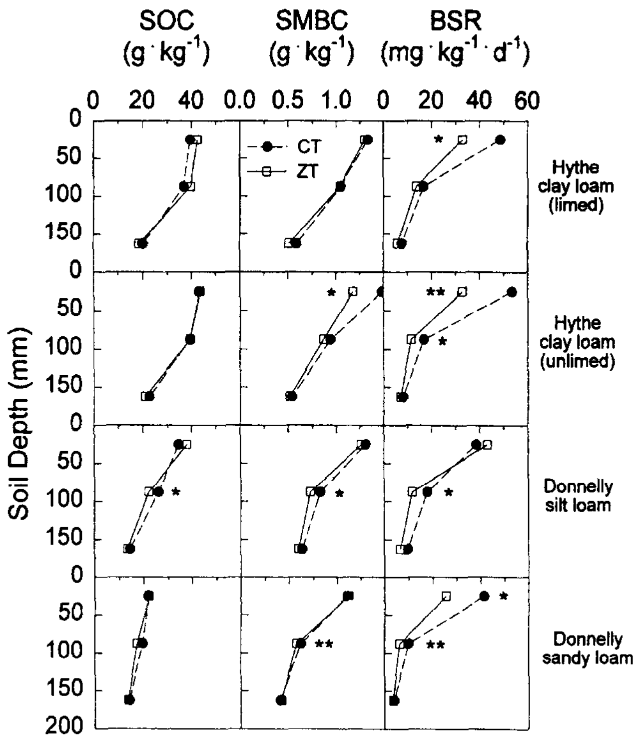

Fig. 1. Depth distribution of soil organic carbon (SOC), soil microbial biomass carbon (SMBC), and basal soil respiration (BSR) as affected by tillage regime (CT, conventional tillage; ZT, zero tillage) and soil type. (*, **, and *** indicate significance between tillage regimes at $P \leq 0.1$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

loam, $187\,g\,m^{-2}$ in the silt loam, and $157\,g\,m^{-2}$ in the loam. At the 0–50 mm depth in the unlimed clay loam and at the 50–125 mm depth in the silt loam and loam, SMBC was higher in CT than in ZT (Fig. 1). Lower SMBC with ZT compared with CT at a depth of 0–50 mm in the unlimed clay loam is in contrast with previous results from similar (Carter and Rennie, 1982) and more temperate, humid regions (Doran, 1987; Franzluebbers, A.J. et al., 1994). Similar SMBC concentration between tillage regimes at the 0–50 mm depth in the limed clay loam, silt loam, and loam was also found for soils in Saskatchewan and Alberta (Carter and Rennie, 1982) and Illinois and Nebraska (Doran, 1987). Greater or equal SMBC concentration with CT than with ZT at a depth of 50–125 mm is consistent with observations reported in these previously cited studies and can be attributed to differences in residue placement.

The portion of SOC as SMBC at a depth of 0–50 mm was significantly greater under CT than under ZT averaged across the four soils and in the clay loams (Table 2). To a depth of 200 mm, the portion of SOC as SMBC was not different between tillage regimes in any of the soils. In a clay loam from Saskatchewan, the portion of SOC as SMBC was larger under ZT than under CT at a depth of 0–100 mm, but not different between tillage regimes in three other soils (Carter and Rennie, 1982). These results

Table 2
Relationships of biological properties to soil organic C and soil microbial biomass C as affected by soil depth, soil type, and tillage regime

Soil type	0–50 mm		50–125 mm		125–200 mm		0–200 mm	
	CT	ZT	CT	ZT	CT	ZT	CT	ZT
Portion of soil organic C as microbial biomass (mg SMBC g^{-1} SOC)								
Hythe clay loam (limed)	33.8 *	30.7	28.8	26.2	29.2	27.4	30.2	27.8
Hythe clay loam (unlimed)	34.5 *	27.2	23.9	22.1	24.7	25.3	26.8	24.4
Donnelly silt loam	39.7	33.1	31.9	32.6	44.3	44.8	37.4	36.0
Donnelly loam	50.5	50.7	32.3	33.8	29.0	31.2	35.8	37.4
Mean	39.6 *	35.4	29.2	28.7	31.8	32.2	32.5	31.4
Portion of soil organic C as basal soil respiration (mg BSR-C g^{-1} SOC per day)								
Hythe clay loam (limed)	1.25 *	0.77	0.46 *	0.34	0.39	0.33	0.64 *	0.46
Hythe clay loam (unlimed)	1.24 **	0.76	0.43 **	0.29	0.36	0.34	0.62 **	0.44
Donnelly silt loam	1.15	1.13	0.69 **	0.52	0.69	0.50	0.82	0.71
Donnelly loam	1.89 **	1.15	0.53 *	0.37	0.30	0.27	0.79 **	0.54
Mean	1.38 *	0.95	0.53 ***	0.38	0.43	0.36	0.72 **	0.54
Relationship of net N mineralization to soil organic C (mg N g^{-1} SOC per 24 days)								
Hythe clay loam (limed)	0.63 *	0.82	0.46	0.49	0.31	0.37	0.46	0.55
Hythe clay loam (unlimed)	0.84	0.96	0.60 **	0.53	0.41	0.28	0.62	0.59
Donnelly silt loam	1.12	1.60	0.65	0.65	0.67	0.46	0.78	0.90
Donnelly loam	0.61 *	1.69	0.77	0.70	0.29	0.38	0.57 *	0.85
Mean	0.80	1.27	0.62	0.59	0.42	0.37	0.61	0.72
Specific respiratory activity (mg BSR-C g^{-1} SMBC per day)								
Hythe clay loam (limed)	37.0 *	25.2	15.8 *	13.0	13.6	12.0	21.1 *	16.7
Hythe clay loam (unlimed)	36.1 **	27.9	17.8 *	13.3	14.9	14.0	23.2 ***	18.1
Donnelly silt loam	29.3	34.3	21.6 *	16.1	15.5 *	11.2	22.1 *	19.8
Donnelly loam	37.9 **	22.6	16.1 **	11.0	10.1	8.5	22.2 ***	14.5
Mean	35.1	27.5	17.8 **	13.3	13.5 *	11.4	22.1 *	17.3
Relationship of net N mineralization to soil microbial biomass C (mg N g^{-1} SMBC per 24 days)								
Hythe clay loam (limed)	18.8 *	26.6	15.9	18.5	10.9	13.4	15.2 *	19.9
Hythe clay loam (unlimed)	23.9	35.2	25.2	23.9	17.6	12.3	23.1	24.2
Donnelly silt loam	26.9	48.0	20.3	20.2	15.0	10.5	20.6	24.8
Donnelly loam	12.6	33.6	23.5	20.6	10.3	12.2	16.0 *	22.8
Mean	20.5 *	35.8	21.2	20.8	13.4	12.1	18.7 *	22.9

*, **, and *** indicate significance between tillage regimes at $P \leq 0.1$, $P \leq 0.01$, and $P \leq 0.001$, respectively.
CT is conventional tillage; ZT is zero tillage.

indicate that ZT with annual crops in the cold, semiarid Canadian Prairies has little detectable increase in soil quality (i.e. SMBC and SOC), at least before 16 years.

BSR at a depth of 0–50 mm under CT was 48% greater than under ZT in the limed clay loam, 63% greater in the unlimed clay loam and the loam, and not different between tillage regimes in the silt loam (Fig. 1). At a depth of 50–125 mm, BSR was 45 ± 16% greater under CT than under ZT for all soils. At a depth of 125–200 mm, BSR was not different between tillage regimes. Relative differences between tillage regimes in cumulative C mineralization were similar to those for BSR (Tables 1 and 2). Differences between tillage regimes in BSR and cumulative C mineralization were greater than differences in SMBC or SOC, indicating their greater sensitivity to C substrate availability. When normalized to the amount of SOC present (i.e. millimeter of BSR-C per gram of SOC per day), the rate of respiration averaged across soils was greater under CT than under ZT at depths of 0–50 and 50–125 mm, but not different at 125–200 mm (Table 2). When normalized to the amount of SMBC, the rate of respiration (i.e. specific respiratory activity) was greater under CT than under ZT for all soils at all depths, except at 0–50 mm in the silt loam (Table 2). Greater portions of SOC and SMBC as BSR under CT than under ZT indicate greater accumulation of potentially more active and decomposable SOC in field-disturbed cultivated soil, which therefore, may actually have a slower in situ decomposition rate than soil under ZT in this climate. Perhaps greater soil moisture conservation with ZT in the spring (Table 1) and throughout the growing season (M.A. Arshad, unpublished data, 1995) in this semiarid climate has resulted in greater in situ decomposition of crop residues and native SOM than under CT, in which soil is prone to more frequent and rapid drying. Since cultivation is shallow in these soils (greater than or equal to 150 mm), much of the crop residues that are incorporated remain near the drier soil surface, similar to conditions normally associated with residue placement with ZT. Thus, decomposition appears to have proceeded to a further stage under ZT than under CT resulting in lower CO_2 evolution under standard laboratory conditions. The seemingly increased in situ decomposition of organic material in ZT, however, does not appear to have enhanced the size of the microbial community (i.e. SMBC).

Net N mineralization, averaged across soils, at a depth of 0–50 mm was 66% greater under ZT than under CT (Table 1), reflecting differences in crop residue placement. There were no differences in net N mineralization between tillage regimes at the 50–125 and 125–200 mm depths. Owing to the large effect at the soil surface, net N mineralization averaged 20% greater at a depth of 0–200 mm. The relationships of net N mineralization to SOC and SMBC also indicated a more labile mineralizable N pool under ZT than under CT at a depth of 0–50 mm, but not at other depths (Table 2). While the total and labile C pools tended to be larger under CT than under ZT, the labile N pool was significantly larger under ZT. A larger labile N pool in ZT than in CT was also observed in soils of other cold, semiarid regions (Carter and Rennie, 1982) as well as in soils in warmer, more humid regions (Doran, 1987; Franzluebbers, A.J. et al., 1994). The labile N pool may have been reduced under CT compared with ZT owing to more frequent drying and wetting, which can increase lignification and incorporation of N compounds into ligno-polymers (van Soest, 1982). Under controlled conditions, net N mineralization from plant material was 30% less under frequent drying and wetting than under continuously moist conditions, while C mineralization was unaffected by such treatment (Franzluebbers, K. et al., 1994).

Sensitivity of soil properties to field variation and tillage treatment was greatest for specific respiratory activity, cumulative C mineralization, and water-filled pore space, which were all more sensitive ($P \leq 0.05$) than SOC. Measurement of the more active fraction of SOM, therefore, appears to be justified to monitor changes in SOM dynamics owing to land management practices. However, as pointed out by Biederbeck et al. (1994), measurement of a suite of soil properties will produce a more comprehensive evaluation of management effects on SOM dynamics.

4. Summary and conclusions

Total and active soil C and N pools were greatest near the soil surface and decreased with depth under both CT and ZT. Soil under ZT contained similar quantities of inorganic soil N, SOC, and SMBC, but was denser and wetter than under CT. However, the most active soil C and N pools measured (i.e. C and N mineralization) indicated that soil under ZT contained a smaller portion of labile organic C, but a larger portion of labile organic N than under CT. Smaller quantities of mineralizable C under ZT than under CT, which is contrary to previously reported results from more temperate and humid regions, may have been a result of the dry soil environment when tilled limiting C turnover. The limited opportunities during the year that decomposition can occur and the greater soil moisture in ZT, therefore, would support our observations of similar or greater active soil C pools under CT compared with ZT.

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